National Defence
Défense nationale

DEFENCE AND CIVIL INSTITUTE OF ENVIRONMENTAL MEDICINE

Canada

NOVEMBER 1985 DCIEM No. 86-R-01

DIAGNOSIS OF SIMULATOR SICKNESS IN THE CF-18 WST

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Abstract

The purposes of this report are to identify potential causes for simulator sickness in the CF-18 Weapons System Trainer (WST), and to provide a means of estimating the extent of the problem. Reported here is an analysis of visual system features which indicates that the WST has considerable potential for generating simulator sickness. Symptoms of simulator sickness and their possible effects on safety and training effectiveness are discussed. The development of a questionnaire to assess the scope and time course of an individual's simulator sickness is described and some objective observations are suggested to validate the questionnaire results. Data gathered by these means should help provide a rational basis for flight restrictions following simulator training on the WST.

Diagnosis of Simulator Sickness in the CF18 WST

Introduction

Simulator sickness is a relatively new phenomenon associated with the use of simulators which provide visual cues for spatial orientation. The term "simulator sickness" refers to a number of symptoms which may occur during or after training on a simulator. Some of the symptoms are similar to those of motion sickness; others are symptomatic of perceptual adaptation. The operational significance of simulator sickness is that it may compromise training and may affect safety in the air and on the ground as the effects of simulator sickness may persist or arise several hours after the training session.

The most widely accepted explanation for simulator sickness is the theory of sensory conflict (for a summary, see [1]). The basic idea is that the simulator provides visual, vestibular and proprioceptive sensations which conflict either with each other or with those in memory and that nausea is a natural physiological response induced by discordant information about orientation. Figure 1 is a simple, schematic diagram of human information processing. It shows that visual, vestibular and non-vestibular proprioceptive inputs from the senses are integrated and compared during perception, and that these activities also receive input from long term memory. One goal of these processes is to assess orientation, another is to guide muscle behaviour. Active movements in turn stimulate the senses thereby completing the feedback loop. Normally, information about body orientation and movement is concordant, but in a simulator it

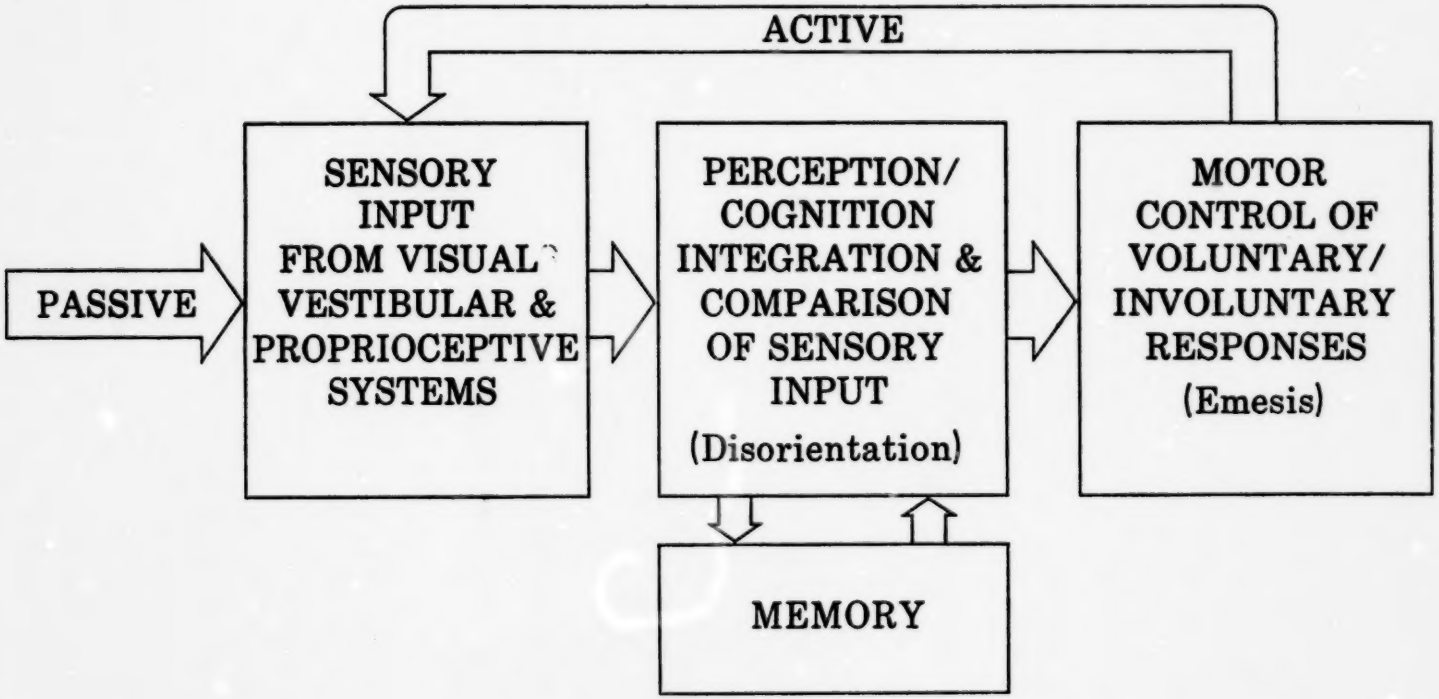
ACTIVE
PASSIVE
SENSORY INPUT FROM VISUAL VESTIBULAR & PROPRIOCEPTIVE SYSTEMS
PERCEPTION/ COGNITION INTEGRATION & COMPARISON OF SENSORY INPUT (Disorientation)
MOTOR CONTROL OF VOLUNTARY/ INVOLUNTARY RESPONSES (Emesis)
MEMORY

Figure 1: A Schematic Diagram of Human Information Processing

is possible that the normal real-world relationships can be violated. For instance, the trainee may experience vection (i.e., perceive himself as moving) as a result of visual stimulation while simultaneously receiving vestibular sensations which indicate that he is static; this situation is typical of simulators which lack motion platforms but have compelling visual displays. Such sensory conflict may produce disorientation and possibly emesis.

A comprehensive review [2] of the etiology, symptomatology and incidence of simulator sickness was undertaken recently by the US National Research Council Committee on Human Factors. Other background papers include the work of Kennedy, Frank, & McCauley [3], and Frank, Kennedy, Kellogg, & McCauley [4]. A germane finding is that the highest incidence of simulator sickness has been reported for air combat manoeuvres training with a fixed base simulator; 88% of the trainees experienced symptoms [5]. The relevance of this finding is that the WST has a fixed base and is used for air combat manoeuvres training. This paper is not intended to provide an additional summary of the literature; rather the purposes of this report are to identify potential causes for simulator sickness in the CF-18 Weapons System Trainer (WST), and to provide a means for diagnosing the extent of the problem. The latter involves the development of a questionnaire for data gathering and the specification of complementary objective measures to help define the scope and time-course of simulator sickness.

It should be noted that the problem of simulator sickness is not necessarily specific to the WST. It may also be a concern in training with the CF-18 Operational Flight Tactics Trainers (OFTT) at CFB Baden and CFB

Bagotville. Simulator sickness may also be a problem in other aircraft simulators, such as the C-130 (Hercules) trainer commissioned recently at CFB Trenton. For this reason, the diagnostic techniques described here are as general as possible. [1]

Background

In July, 1984 DCIEM was asked by AIRCOM [6] to assist in developing a questionnaire to be administered to aircrew after simulator flights on the CF-18 WST recently commissioned at the Aircrew Training Centre at CFB Cold Lake. The intended use of this questionnaire is to help provide a rational basis for flight restrictions following simulator training. Concern about simulator sickness in the WST was generated as a result of pilot experiences during WST Availability Demonstrations. In a report [7] provided by the Operational Requirements Manager for the CF-18 it was noted that:

> The A-Demo exercised all components of the WST by scheduling specific types of anticipated training missions. This represented our first opportunity to exercise the system in the anticipated operational BFM and ACM training modes... During these exercises my staff noted some of the anticipated psychophysiological effects. These effects occurred during relatively short exposures to high dynamic training exercises. (p. 1)

[1] Note, too, that the problem of simulator sickness is not limited to aircraft simulators; it is a potential problem with maritime and land simulators as well.

As a result of this incident and preliminary discussions with USN personnel regarding their experiences with a variety of flight simulators, a directive [8] was issued by Air Command which placed a restriction on flying after simulator exposure. No pilot was to fly the CF-18 solo for twelve hours following simulator training. This restriction was subsequently revised on the basis of further contacts with USN F-18 flight surgeons at NAS Leemore, California [9]. The twelve hour restriction is now applied only to the introductory flight in the WST and the first flight involving prolonged air combat manoeuvres (ACM). Other phases of training have a two hour restriction. Beyond these minimum restrictions pilots are to assume individual responsibility for fitness to fly. The present guidelines are seen as interim measures until more definitive data are gathered on the phenomenon. It is important to establish a rational basis for flight restrictions since a proper balance must be struck between concerns for flight safety and training requirements.

Potential causes for WST simulator sickness

A site visit to the CF-18 Aircrew Training Centre was made in October, 1984, to assess the potential of the WST for causing simulator sickness. The following paragraphs identify and discuss features of WST training which could evoke simulator sickness. Since visual parameters are considered to play the most important role in generating simulator sickness, particular attention is given to characteristics of the WST visual system and related factors.

The visual system of the WST provides an extremely wide field of view [FOV]. Images of terrain and other aircraft are projected onto a 40' diameter dome. This affords the pilot a 360 degree horizontal by 270 degree vertical FOV. This characteristic of the WST is important since it provides extensive stimulation of the pilot's peripheral visual system, which is important in assessing dynamic and orientation information [10]. The implication is that the WST provides a very strong experience of vection. Anecdotal reports confirm that the visual display of the WST is extremely compelling in this respect; pilots report that they are unwilling to leave the cockpit if the visual display is frozen in an off-level position at the end of a training session, for example. This example is particularly vivid in view of the fact that the WST is not equipped with a motion platform. Thus both the static and dynamic visual cues for orientation may conflict strongly with those of the vestibular system.

Lags in the control/display dynamics are also a possible cause for simulator sickness. Incongruities seem to exist between the response characteristics of the WST and those of the CF-18. Visual system lag in the WST has been measured by the Aerospace Engineering and Test Establishment (AETE) in response to the occurrence of pilot induced oscillations (PIOs) in landing and formation flying tasks. PIOs are associated with system delay in simulated tasks which require precise visual-motor control [11]. AETE estimated the lag between control input and visual display response to be about 350 msec [12]. This figure compares unfavourably with the control sensitivity of the aircraft which is described by pilots as producing "instantaneous g", and is excessive when compared to recommended allowable delays found in the literature.

Richard and Puig (cited in [10]) reviewed available research literature and collected user opinion to conclude that such visual system delays should not exceed 125 msec.

Delays in generating a visual scene and phase shifts between visual and proprioceptive cues arising from the g-seat and g-suit are possible sources of sensory conflict, as are asynchronies between instruments (e.g., the HUD) and out-of-cockpit visual cues. The importance of lag to the incidence of simulator sickness is clearly expressed by the following excerpt [2, p. 11]:

> Experienced pilots have learned a set of temporal and spatial patterns in the aircraft related to control stick inputs and the resultant visual, vestibular, and proprioceptive feedback of acceleration information. In the simulator, they are confronted with a new set of temporal and spatial patterns, i.e., lags, rise times, washout, etc. This discrepancy is probably the main source of simulator sickness.

A related problem is the fidelity of control/display dynamics. Control "feel" may differ between the aircraft and simulator due to the advanced avionics aboard the aircraft. These avionics are programmable and hence may change with time, whereas software updates on the simulator fall behind.

Other features of the visual system which may contribute to simulator sickness in the WST include poor resolution, flicker and optical distortions. The visual system of the WST is a hybrid built by McDonnell Douglas; a Vital IV image generator is used for presenting air targets and runway while a one-of-a-kind Dynamic Earth Sky (DES) system is used for presenting air, haze

band, and ground separation. The air targets displayed by the Vital IV system are detailed, three-dimensional, shaded representations of friendly/foe aircraft. They are superimposed upon the background provided by the DES system. To achieve wrap-around, three pairs of projectors are required. One pair is needed for each of two possible targets and one pair is needed for the DES arrangement. Visual discontinuities exist at the display boundaries for the projectors. For example, a seam between fore and aft projections of the DES is apparent; colours are not equally saturated across the boundary, some "shearing" of the visual display is evident, and target aircraft blink noticeably as they cross the boundary.

Another example of a visual anomaly is that the image in the HUD is not focused at the same optical distance as the surface of the dome. Double images result. These and other features of the WST visual system (e.g., poor resolution of ground terrain) may help instigate simulator sickness as may the use of certain instructional features which have visual effects. For example, the "freeze" and "reset" functions can be very disconcerting because they provide very unusual visual stimulation.

An important point to keep in mind is that no single factor may be sufficient to produce simulator sickness but that their effects may combine. Moreover, a number of additional factors may aggravate incidence. First, the student population consists of highly experienced pilots. This is an important consideration since the research literature (e.g., [13]) indicates that experienced pilots may be *more* susceptible to simulator sickness than inexperienced pilots. The type of training conducted on the simulator is another important factor;

ACM training requires very dynamic head movements. These movements are known to exacerbate simulator sickness [2]. Heavy pilot workload, typical of ACM sessions, is also considered to be provocative [2].

However, informal interviews with instructor and student pilots indicated that simulator sickness is not prevalent among CF-18 trainees despite the fact that there seem to be a large number of potential causes. Two ready explanations for this paradoxical situation are: (i) ACM sessions had not yet been conducted on the WST due to equipment failures during the first course serial; and (ii) there is a natural reluctance on the part of the pilots to admit to simulator sickness.

It is clear from the foregoing analysis that WST visual system parameters and the type of training conducted on the simulator offer strong potential for simulator sickness. Safety in the air and on the ground may be affected. As well, training effectiveness may be diminished. Learning motivation may suffer. Transfer-of-training may also be negatively affected.

In the absence of information on the incidence of simulator sickness among WST trainees, some tentative, recommended countermeasures are restated (from [2]):

(i) Indiscriminate use of the "freeze" function should be avoided. In particular, the simulator should not be frozen in an off-level attitude at the end of the training session and the dome should be flood lighted to assist reorientation.

(ii) Indiscriminate use of the "reset" function should be avoided. The dome should be "blanked" during reset, or the trainees should be instructed to close

their eyes during reset.

(iii) Prolonged, intense training sessions should be avoided. Training sessions should not exceed 1 hour duration.

(iv) Trainees should be briefed about the possibility of simulator sickness and it should be recommended that head movements be kept to a minimum if the trainee is susceptible to simulator sickness.

(v) Medications such as flu shots, alcohol, etc., should be avoided prior to simulator flights.

It is tempting to consider more drastic measures to counteract simulator sickness such as the addition of a motion platform and/or improved visuals, but the worth of these enhancements is debatable. It is instructive to note that simulator sickness may occur with or without a motion platform [2], and that motion platforms cannot match the extreme manoeuvres required for high acceleration ACM. The usefulness of a high resolution visual system is also questionable since it has been suggested that increased scene detail may actually help promote simulator sickness [2]. The most fruitful avenue for hardware/software change would likely involve improving and coordinating the visual system response of the WST.

Unfortunately, it is not possible to predict the incidence or severity of simulator sickness by examining the WST and its use since behavioural research does not yet support a quantitative model. At best, it is possible only to implicate precipitating conditions; clearly, there are a large number of these. The lack of a quantitative model, or theory, necessitates an empirical approach to assess the degree of simulator sickness. The following section of this report

provides a method.

Diagnosing Simulator Sickness

The purposes of this section are to provide a set of questionnaires for assessing the extent of simulator sickness among CF aircrew, to explain the rationale behind questionnaire content, to offer complementary objective measures, and to outline their administration. The set of questionnaires is based on survey materials currently being used by the Naval Training Equipment Center (NTEC) in the US. The NTEC survey represents the most significant effort of its type to gather data about simulator sickness. The questionnaire was designed for use in studies of the 2E6 Air Combat Maneuvering Simulator (ACMS). It should be noted that the RAF Institute of Aviation Medicine has also adopted a modified version of the NTEC questionnaire for distribution to pilots in the UK. In order to provide context for Canadian survey results, and to facilitate international exchange of information, it seemed reasonable to make use of the NTEC and RAF questionnaires. [2]

However, several aspects of the NTEC questionnaires made it desirable to modify them for use in Canada: (i) the NTEC questionnaires contain USN terminology; (ii) some questions are specific to certain occupations in the USN and certain types of simulators; (iii) there is redundancy and a lack of consistency among the symptom names; (iv) the format of the questionnaires

[2] At the annual meeting (July, 1985) of Technical Panel 2 (Training Technology), of Subgroup U (Behavioural Sciences), of TTCP (The Technical Cooperation Program) member nations agreed to exchange scientific information on the topic of simulator sickness.

could be improved; and, (v) the content could usefully be changed in some cases. We have attempted to overcome these difficulties, to provide a survey instrument applicable to a wide range of flight simulators (and trades), and to provide a set of questionnaires for efficiently assessing simulator sickness.

The major products of this effort are four separate questionnaires, contained in Appendix A. It is proposed that they be used as the principal means of collecting data. Each questionnaire has a separate purpose. The first questionnaire, called the *Aircraft/Simulator Flight Experience Questionnaire,* is designed to collect biographical information. The respondent is asked to provide information about occupation, age, flying experience and past incidences of simulator/motion sickness. The purpose of this questionnaire is to provide data which can be correlated with simulator sickness. The questions seek information which is thought to influence incidence.

The second questionnaire is titled the *Immediate Post-Run Questionnaire.* Its purpose is to obtain incidence and severity reports on a wide variety of possible symptoms/reactions. Respondents are simply required to "check" the response which best describes their symptom(s), and to note the events which preceded its occurrence. The list of symptoms represents the more commonly indicated reactions. It was compiled from a survey of thirty articles which is a comprehensive selection of the simulator and motion sickness literature (see Appendix B for details). Included in the literature survey are reviews of simulator sickness [1,2,4], two major reviews of motion sickness [14,15], two reports on the development of motion sickness scales [16,17], and articles on sickness in various kinds of simulators, including driving simulators [18,19], a helicopter

simulator [20], and flight simulators [21,22,23]. Table 1 lists the prevalent symptoms and their frequency.

Most of the symptom names in Table 1 have been used in the questionnaire. However, some were eliminated to reduce redundancy (e.g., fatigue/tiredness) and others added to improve specificity (e.g., physical/mental fatigue). Note that "stomach awareness" is listed as a stock item on the list; Graybiel [24] discovered that respondents are unwilling to admit to nausea but that they are willing to admit to stomach awareness, a term whose connotation is less negative. Magnitude ratings are employed because of their successful use by Wiker, Kennedy, McCauley and Pepper [17] who studied motion sickness.

TABLE 1: Simulator/motion sickness symptoms mentioned four or more times in thirty articles

Symptom	Frequency	Symptom	Frequency
Nausea	23	Unsteadiness	6
Dizziness	19	Yawning	6
Sweating	18	Burping	5
Headache	17	Eye strain	5
Vomiting	16	Apathy	4
Vertigo	15	Confusion	4
Disorientation	13	Depression	4
Drowsiness	13	Leans	4
Pallor	12	Malaise	4
Salivation	12	Nystagmus	4
Stomach Awareness	11	Retching	4
Discomfort	8	Tiredness	4
Fatigue	7	Warmth	4
Loss of appetite	7		

The items on the questionnaires emphasize effects associated with the visual, balance and motor systems, in keeping with the sensory conflict theory of simulator sickness. Respondents are asked to indicate the actions (for example, manoeuvres) thought to elicit the occurrence of a symptom or reaction. McGuinness, Bouwman, and Forbes [25] report that specific manoeuvres such as a loops and nose high attitudes were reported by pilots to contribute to symptom onset. This questionnaire would be answered immediately after a simulator training session.

Approximately 24 hours later the third questionnaire, the *Delayed Post-Run Questionnaire,* is to be completed. This questionnaire is very similar to the *Immediate Post-Run Questionnaire* but asks the respondent to indicate the duration of any symptoms/reactions experienced during the 24 hour period, rather than the manoeuvre(s) eliciting them. The purpose is to collect data on the longevity of reactions and the incidence of delayed-onset reactions. Finally, a *Summary Questionnaire* is provided to collect the trainee's impressions of the simulator and information about his experiences during certain post-simulator activities. This questionnaire will be used to determine whether simulator sickness varies with perceived simulator fidelity. A second purpose is to discover if any simulator after-effects are elicited while driving or in flight or whether post simulator activities are effective in offsetting after-effects. Kennedy, Frank, McCauley, Bittner, Root and Binks [26] for instance have reported an apparent simulator-related effect on driving. They relate the experience of a pilot who found it necessary to pull off to the side of the road to avoid being a driving hazard after flying a helicopter simulator for four hours. Sleep [25] and activi-

ties which involve eye-hand coordination [2] may facilitate readaptation to a normal environment.

Ideally, the immediate and delayed post-run questionnaires would be completed at points in the course serial where simulator sickness is thought to be most acute. For CF-18 training this would likely be the first BFM and ACM sessions. All trainees in the course serial should be asked to participate voluntarily. A consent form (Appendix C) is provided for this purpose. As recommended in the literature [27], the consent form warns participants of possible adverse effects of the simulator.

The questionnaires have been designed to be administered by a trained interviewer. The interviewer's job would be: to manage data collection in a consistent, objective, confidential way; to answer questions; to occasionally query trainees about their experiences; and to observe the trainees both before and after a simulator run. A small set of "objective" measures is proposed to assist the interviewer in collecting observational data. It includes observations of pallor, sweating, drowsiness, nystagmus and balance (see Appendix D). It is highly recommended that these tests be administered in conjunction with the questionnaires, and that they be given immediately before and after a training session so that the effects of simulator may be determined. The reason for including the tests is to provide some objective data with which to validate the questionnaire results.

Some Objective Tests - Although objective techniques have been devised, the most common means of assessing skin pallor is subjective rating (for a review,

see 28). Cold sweating has been measured this way although galvanic skin response and its variations have often been used [18,19,29]. In order to avoid intrusion, Cramptom's [30] procedure has been chosen.

Several papers indicate drowsiness as a symptom of simulator sickness [4,17,22] yet little is revealed about how this symptom is identified or its severity rated. Graybiel and Knepton [31] identified the "sopite syndrome" as consisting of yawning, drowsiness, disinclination for work (physical or mental) and lack of participation in group activities. However, the dearth of expository information on this topic means that observer opinion must be relied upon.

In contrast, a large number of procedures exist for measuring loss of balance. They are distinguished on the basis of whether the participant is walking or standing, or whether the participant has eyes open or closed/blindfolded. A popular test, typical of its kind, is the WOFEC (Walk On Floor Eyes Closed), which requires participants to walk heel-to-toe, with arms folded against their chests [32,33]. The number of steps properly taken before sidestepping, stopping, opening the eyes, or unfolding the arms is taken as the trial measure. Another popular test is the Sharpened/Modified Romberg [14,33,34] which requires the participant to stand with one foot in front of the other. These tests for loss of balance have been chosen because it has been found that their combined use offers an economical and valid means of assessing postural equilibrium [33] and because precise instructions for their administration are available.

Nystagmus consists of rapid involuntary oscillations or rythmical movements of the eyes [35]. Nystagmus may be observed directly although mechanical means have also been employed [e.g., 36]. The noninvasive technique of Adams [37] is preferred in the current circumstances.

Scheduling of Questionnaires - It is estimated that the *total* amount of time required to complete the questionnaires and to participate in objective testing would be approximately 90 minutes. This amount of time would be distributed over several occasions. For easy reference, Table 2 summarizes the survey design, and estimates the amount of time required to complete various phases of the study.

TABLE 2: Proposed Scheduling of Questionnaires

Serial	Activity	Duration (min)
1	Flight experience questionnaire	5
2	Objective tests	15
3	BFM (first session)	
4	Immediate post-run questionnaire & Objective tests	20
5	(24 hour delay)	
6	Delayed post-run questionnaire	5
7	Summary questionnaire	5
8	Interpolated training - several weeks	
9	Objective tests	15
10	ACM (first session)	
11	Immediate post-run questionnaire & Objective tests	20
12	(24 hour delay)	
13	Delayed post-run questionnaire	5
	Total:	90

Conclusions/Recommendations

In conclusion, it is recommended that the questionnaires and observational tests described in this report be administered to WST trainees by DCIEM personnel, or persons contracted by DCIEM, in order to maintain impartiality. Also, it is recommended that the data be analysed by DCIEM so that the results may be interpreted within the context of laboratory research, the purpose of which would be to corroborate the relationship between symptoms and observable measures by testing subjects without vested interest. These recommendations are important since they attempt to counter trainee resistance to admit to simulator sickness and subsequently limit doubt about the validity of the information provided by the questionnaires. The approach should provide a rational basis for flight restrictions as well as an objective means of assessing the potential value of possible modifications to the WST.

Acknowledgements

We gratefully acknowledge the assistance of D. Turner, for providing preliminary modifications to the NTEC questionnaires, and R. Slater, for a preliminary literature review. Thanks are also due to Captains R. Yanow and C. Hadfield for reviewing draft questionnaires, and to Dr. K. Money for reviewing a draft report.

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Appendix A

Simulator Sickness Questionnaire

AIRCRAFT/SIMULATOR FLIGHT EXPERIENCE QUESTIONNAIRE

Respondent Code Number	Date	Age	Year Wing Standard Obtained	Current Occupation (Write-in)

Aircraft/Simulator Flight Hours (All Types)							
Military Aircraft		Military Simulators		Civilian Aircraft		Civilian Simulators	
Fixed	Rotary	Fixed	Rotary	Fixed	Rotary	Fixed	Rotary

PREVIOUS MILITARY *AIRCRAFT* FLIGHT EXPERIENCE

	Basic Training		Advanced Training		OTU Training		Operational Experience	
	Fixed	Rotary	Fixed	Rotary	Fixed	Rotary	Fixed	Rotary
1. Estimate the total **number** of missions you have instructed or crewed during the denoted phases of your military non-simulator flight career.								
2. With reference to your total military missions, estimate the **number** of missions on which you experienced nausea.								
3. With reference to your total military missions, estimate the **number** of missions on which you became spatially disoriented (for example, leans).								

PREVIOUS MILITARY *SIMULATOR* FLIGHT EXPERIENCE

	Simulator 1	Simulator 2	Simulator 3	Simulator 4	Simulator 5	Simulator 6
4. Write-in Simulator Model/ Identifier Code for military simulators you have instructed or crewed.						
5. Estimate the total **number** of runs instructed or crewed per simulator.						
6. Estimate the **average** duration of the runs (minutes).						
7. Estimate the **number** of runs on which you experienced simulator sickness.						
8. Estimate the **number** of runs on which you became spatially disoriented (for example, leans).						

Respondent Code Number	Date

PREVIOUS CIVILIAN *AIRCRAFT* FLIGHT EXPERIENCE

	Training Experience		Qualified Experience	
	Fixed	Rotary	Fixed	Rotary
1. Estimate the total **number** of flights you have instructed or crewed during the denoted phases of your civilian non-simulator flight career.				
2. With reference to your total civilian flights, estimate the **number** of flights on which you experienced nausea.				
3. With reference to your total civilian flights, estimate the **number** of flights on which you became spatially disoriented (for example, leans).				

PREVIOUS CIVILIAN *SIMULATOR* FLIGHT EXPERIENCE

	Simulator 1	Simulator 2	Simulator 3	Simulator 4	Simulator 5	Simulator 6
4. Write-in Simulator Model/Identifier Code for civilian simulators you have instructed or crewed.						
5. Estimate the total **number** of runs instructed or crewed per simulator.						
6. Estimate the **average** duration of the runs (minutes).						
7. Estimate the **number** of runs on which you experienced simulator sickness.						
8. Estimate the **number** of runs on which you became spatially disoriented (for example, leans).						

IMMEDIATE POST-RUN QUESTIONNAIRE

Respondent Code Number	Date	Current Time	Simulator Run Start Time	Simulator Run Stop Time	Simulator Run Number

Questionnaire Instructions:

Check the appropriate block to indicate the magnitude of any symptoms or reactions that you may have experienced **during or immediately after** the simulator run, then record the action(s) which you feel elicited the symptom/reaction.

If you experienced any unusual symptoms or reactions that are not listed below, record in the blank spaces at the bottom of the table, rate the magnitude of the symptoms/reactions, and record the action(s) eliciting their onset.

Symptom/Reaction	Check One				Action Eliciting Onset of Symptom/Reaction (Write-in)
	Magnitude of Symptom/Reaction				
No. Description	Not Present	Mild	Moderate	Severe	
1. general loss of well-being					
2. warmth					
3. headache					
4. physical fatigue					
5. stomach awareness			Discomfort	Nausea	
6. vomited (emesis)		Once	Twice	Three More	
7. loss of balance					
8. eye strain					
9. blurred vision					
10. loss of depth perception					
11. inverted vision					
12. visual flashbacks					
13. apathy					
14. mental fatigue					
15. drowsiness					
16. confusion					
17. dizziness					
18. vertigo					
19. leans					
20. spinning sensations-rotation					
21. translatory sensations					
22. disorientation					
23. after-sensations of motion					
24. difficulty in fine movements					
25. loss of appetite					
26. excessive salivation					
27. burping					
28. movement of visual scene					
29.					
30.					

DELAYED POST-RUN QUESTIONNAIRE

Respondent Code Number	Date	Current Time	Simulator Run Start Time	Simulator Run Stop Time	Simulator Run Number

Questionnaire Instructions:

This is a follow-up to determine if you experienced any after-effects that you would attribute to your previous simulator run. Place a check mark in the appropriate block under the "Magnitude of Symptom/Reaction" heading and another check mark in the appropriate "Duration of Symptom/Reaction" block when a symptom/reaction was present.

If you experienced any unusual symptoms or reactions that are not listed below, record in the blank spaces at the bottom of the table, then rate the magnitude and duration of the symptom/reaction.

Symptom/Reaction	Check One				Check One				
	Magnitude of Symptom/Reaction				Duration of Symptom/Reaction				
No. Description	Not Present	Mild	Moderate	Severe	Less Than ½ hr	½ -1 hr	1-4 hrs	4-12 hrs	Longer Than 12 hrs
1. general loss of well-being									
2. warmth									
3. headache									
4. physical fatigue									
5. stomach awareness			Discomfort	Nausea					
6. vomited (emesis)		Once	Twice	Three/More					
7. loss of balance									
8. eye strain									
9. blurred vision									
10. loss of depth perception									
11. inverted vision									
12. visual flashbacks									
13. apathy									
14. mental fatigue									
15. drowsiness									
16. confusion									
17. dizziness									
18. vertigo									
19. leans									
20. spinning sensations-rotation									
21. translatory sensations									
22. disorientation									
23. after-sensations of motion									
24. difficulty in fine movements									
25. loss of appetite									
26. excessive salivation									
27. burping									
28.									
29.									
30.									

SUMMARY QUESTIONNAIRE

Respondent Code Number	Date	Time

Instructions for Questions 1 to 7:

The function of this questionnaire is to gain your opinions as an experienced aviator on the overall performance of the simulator. Circle the number below each question which best corresponds to your rating.

1. Did this simulator give you a sensation of motion?

1	2	3	4	5	6	7	8	9	10
No sensation of motion									Strong sensation of motion

2. Did this simulator feel like a real aircraft in terms of its control/response characteristics?

1	2	3	4	5	6	7	8	9	10
Poor simulation of real aircraft									Indistinguishable from real aircraft

3. Did this simulator have any unusual time lags between the time you applied control input and the time actual motion of the simulator base or visual scene occurred?

1	2	3	4	5	6	7	8	9	10
No unusual time lag									Excessive time lag

4. Did this simulator generate visual cues of motion that were realistic?

1	2	3	4	5	6	7	8	9	10
Poor simulation of flight visual motion									Identical to flight visual motion

5. Did this simulator generate physical cues of motion that were realistic?
(e.g. as provided by a motion platform, g-suit, etc)

1	2	3	4	5	6	7	8	9	10
Poor simulation of flight physical motion									Identical to flight physical motion

6. Did you experience a change in your sense of vulnerability following simulator training?

1	2	3	4	5	6	7	8	9	10
More Vulnerable									Less Vulnerable

7. Have you ever had any motion after-effects following real aircraft flights?

10	20	30	40	50	60	70	80	90	100
% or fewer flights									% of flights

8. Did any activity performed after simulator training (for example, playing crud) relieve symptoms? Please list below. (Use back of page if more space needed for Ques. 8, 9, 10)

9. If you have flown in an aircraft after a simulator session (on the same day), describe any unusual sensations you experienced in the aircraft.

10. If you have driven a motor vehicle after a simulator session (on the same day), describe any unusual sensations you experienced in the vehicle.

Appendix B

Summary of Literature Review

Part A:

LIST OF SIMULATOR/MOTION SICKNESS SYMPTOMS MENTIONED IN ARTICLES

Abdominal Problems Reported by Subject or Observed by Others

Vomiting, Emesis: [5], [6], [7], [8], [9], [11], [12], [13], [14], [15], [16], [17], [18], [21], [22], [29]

Regurgitation: [1]

Retching: [7], [12], [16], [29]

Tendency to Vomit: [18]

Nausea Bordering on Emesis: [6]

Nausea: [1], [3], [4], [5], [6], [7], [8], [9], [11], [12], [13], [14], [15], [16], [17], [19], [21], [22], [23], [24], [27], [28], [29]

Stomach (Epigastric, Substernal) Awareness: [3], [6], [7], [10], [11], [12], [16], [21], [22], [27], [29]

Stomach (Epigastric, Substernal) Discomfort: [3], [12], [21]

Sickness (Feelings): [1], [11], [23]

Malaise: [4], [7], [12], [21]

(General Feeling) of Motion Sickness: [6], [21], [30]

Upset Stomach: [1]

Fullness of Stomach: [6]

Butterflies/Lightness in Stomach: [14]

Stomach Effects: [1]

Gastric Sensations: [9]

Stomach (Abdominal) Cramps: [2], [21]

Burping (Flatulence, Gas, Belching): [6], [11], [21], [27], [29]

Bowel Movement Desire: [16], [29]

Loose Bowels: [21]

Loss of Appetite, Anorexia: [6], [7], [9], [11], [16], [21], [29]

Disinterested in Food: [14]

After Vomiting, Sudden Symptom Relief: [21]

Mouth Problems Reported by Subject or Observed by Others

(Increased) Salivation: [3], [5], [6], [7], [11], [12], [14], [16], [21], [22], [27], [29]

Decreased Salivation: [12]

Dry Mouth: [16], [22]

Mouth Excessively Moist or Dry: [21]

(Increased) Swallowing: [3], [21]

Loss of Energy Reported by Subjects or Observed by Others

Drowsiness: [5], [6], [7], [10], [11], [12], [14], [16], [17], [21], [22], [23], [29]

Soporific Drowsiness: [11]

Apparent Drowsiness: [6]

Fatigue: [6], [7], [8], [11], [12], [20], [21]

Long-term Fatigue: [11]

Mental Fatigue: [8]

Tiredness: [6], [13], [14], [23]

Sleepiness, Somnolence: [21]

Desire to Sleep: [14]

Disrupted Sleep: [8]

Yawning: [6], [16], [17], [21], [27], [29]

Feeling Totally Washed Out: [8]

Weakness: [11], [14], [21]

Knees Weak: [6]

Incapacitation: [11]

Prostration: [21]

Balance and Motor Effects Reported by Subject

Dizziness: [1], [2], [3], [5], [6], [7], [8], [9], [10], [11], [12], [14], [16], [17], [18], [21], [22], [27], [29]

Giddiness: [21]

Light Headed: [14]

General Light Feeling, Almost Like Drunk: [14]

Vertigo: [1], [2], [4], [6], [8], [10], [14], [15], [17], [18], [20], [24], [25], [29], [30]

Sensation of Rotation: [15]

Spinning Sensation: [6], [8], [11]

Spinning While Lying in Bed: [8]

Maneuvering Sensation: [8]

Sensation of Climbing and Turning: [8]

Sensation of Tossing When Lying Down: [16]

(Kinesthetic or Vestibular) Sensation of Motion: [1], [2]

Motion Sensation After-Effects--Memory of Motion: [6]

After Sensation of Simulator Motion: [6]

Feel Movement After Hop: [14]

Observable Balance and Motor Effects

Disorientation: [1], [2], [5], [6], [7], [8], [11], [19], [20], [21], [23], [27], [30]

Spatial Disorientation: [2], [13], [21]

Disorientation when Reset Used: [11]

Orientation Disturbances: [8]

Leans: [6], [8], [10], [11]

Staggers, Sea Legs: [8], [11]

Unsteadiness (in Walking, Gait): [1], [6], [10], [23], [27], [30]

Unstable Walking: [6]

Difficulty Standing/Walking: [6], [12], [16]

(Postural) Instability: [6], [12], [15]

Loss of Static Ability: [18]

Decrements in Postural Equilibrium Walking/Standing: [10]

Postural Disequilibrium: [10], [27]

Postural Problems: [6]

Postural Changes: [11]

Postural Illusions: [12]

Balance Problems: [8]

Imbalance Similar to that After Long Boat/Train Ride: [8]

Motor Imbalance: [8]

Motor Dyskinesia: [6], [8], [11]

Ataxia: [10], [11]

Incoordination: [10]

Incoordination, Particularly in Manual Control: [11]

Decreased Muscular Coordination: [21]

Difficulty Climbing out of Cockpit if Display Frozen Wings-Down: [11]

Effect on Performance Reported by Subjects or Measured by Others

Steering Wheel Reversals, Yaw Deviation: [5]

Decreased Ability to Perform Arithmetic: [5], [21]

Decreased Performance with Electronic Tracking, Pursuit Meter, Hand Dynamometer (Squeezing Ability), Decreased Ability to Estimate Time: [21]

Decreased Spontaneity: [11], [21]

Carelessness: [11], [21]

Loss of Performance: [25]

Attentional Difficulties: [8]

Feeling of Detachment While Driving: [11]

Feeling of Being in Simulator While in Real Helicopter: [11]

Skin and Temperature Effects Reported by Subject or Observed by Others

Perspiration, (Cold) Sweating: [1], [2], [3], [5], [6], [7], [8], [9], [11], [12], [14], [16], [17], [18], [21], [22], [26], [29]

Forehead Perspiration: [5]

Sweating with Nausea: [6]

Pallor: [5], [6], [7], [9], [11], [12], [16], [17], [18], [21], [22], [29]

Flushing: [2], [12]

Subjective Warmth, Temperature Changes: [2], [3], [12], [22]

Coldness of Extremities: [21]

Pain and Other Unpleasant Sensations Reported by Subject

Headache: [5], [6], [7], [8], [9], [10], [11], [12], [14], [16], [17], [18], [21], [22], [23], [27], [29]

Headache-Result of Eye Strain: [13]

Head Fullness: [12]

Other more Migraine-like Symptoms: [11]

(General) Discomfort: [1], [6], [11], [12], [14], [16], [21], [29]

Muscular Tension: [2]

Tingling: [7]

Breathing Changes

Increased Respiration (Ventilation) Rate: [5], [9], [21], [26]

Hyperventilation, Over-ventilation: [7], [12]

Altered Respiration Rate: [5]

Slow Respiration Rate and Shallow Breathing: [21]

Awareness of Breathing: [6], [16]

Aerophagia: [12], [29]

Sighing: [21]

Desire for (Cool) Fresh Air: [11], [21]

Internal Changes Measured by Others

Blood Pressure Disturbances, Changes: [2], [9], [21]

Altered Heart Rate: [5]

Altered Pulse Rate: [9], [21]

Increased Intestinal Peristalsis: [7]

Inhibition of Intestinal Tone: [21]

Duodenal Spasm: [21]

Inhibition of Gastric Motility and Tonus: [21]

Decreased/Increased Gastric Secretion: [21]

Fall of Body Temperature: [21]

Fall of Skin Temperature: [21]

Fall of Mouth Temperature: [9], [21]

Vision

Eye strain: [1], [5], [6], [13], [14]

(Optokinetic) Nystagmus: [2], [9], [12], [15]

Eyeball Jitter: [6]

(Loss of or Change in) Depth Perception: [1], [6]

Blurred Vision: [14], [16]

Double Vision: [14]

Eyes Slow to Focus: [14]

(Difficulty, Problems) Focusing: [6]

Flashbacks (of Visual Experience): [6], [8], [11]

See Screen After Hop: [14]

Replay of SAAC Visual Sequences During Light Mental Activity: [8]

Visual Streaming: [11]

Motion Perceived in the Field-Whirling About Them: [2]

Visual Illusions: [11], [12]

Oculogyral Illusion: [15]

Inversion of Visual Field, Inverted Vision: [6], [8]

Vivid Visual Reactions (Daydreams, Dreams): [8]

Spots Before the Eyes: [27]

Visual Dysfunction: [6], [11]

Vision Problems: [6]

Visual Uncertainty: [21]

Disequilibrium Watching a Movie: [11]

Impairment of Reading: [14]

Eye pressure: [2]

Ocular Imbalance: [21]

Small Pupils: [21]

Dilated Pupils During Emesis: [21]

Emotional and Attitudinal Effects Reported by Subject or Observed by Others

Apathy: [11], [12], [21], [29]

Lassitude: [6], [21]

Lethargy: [21]

Inactivity: [21]

Facies of Great Dejection and Apathy: [21]

(Mental) Depression: [7], [15], [21], [29]

Dejection: [11]

Melancholy: [14]

Feeling Miserable: [21]

Feeling of Disinterest Except in Escaping Motion: [21]

Being Quiet, Subdued: [21]

Social Indifference: [21]

Wish to be Left Alone: [21]

Feeling of Coldness: [21]

Feeling of Isolation: [21]

Dislike of Situation: [1]

Distress and Upset: [11]

Disturbance: [23]

Uneasiness: [5]

Nervousness: [14]

Anxiety: [16], [21]

Characteristic Facies of Anxiety: [12]

Demand to Stop Motion: [18]

Confusion: [6], [11], [21], [27]

Loss of Situational Awareness: [8]

(Feeling of, Feel Close to) Faintness: [1], [22]

Claustrophobia, Feel Closed In (Desire to Escape): [1], [14]

Characteristic Facies (of Motion Sickness): [17], [29]

Unusual Sensitivity to Repulsive Things: [21]

Normal or Increased Alertness: [12]

Part B:

REFERENCE NUMBERS OF ARTICLES CITED IN PART A: GROUPED BY STUDY AND/OR AUTHORS

This appendix joins the reference numbers used in Part A of this Appendix: Simulator/Motion Sickness Symptoms, to the articles in which these symptoms were found. The following articles are grouped under the same number when they report the same study or when the list of authors is virtually the same. We did this to avoid artificially increasing the number of references made to a particular symptom/reaction name.

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Appendix C

Volunteer Consent Form

SIMULATOR SICKNESS STUDY

VOLUNTEER CONSENT FORM

Respondent Code Number

I, _____, agree to participate in this study of simulator sickness. I understand that participation will involve the completion of several questionnaires and the performance of balance tests. I also understand that some individuals have experienced sickness during/after simulator sessions. The interviewer has informed me that I may withdraw from the study at any time. I was also informed that I could leave the simulator if I ever feel too ill to continue. I understand that my answers on the questionnaires and results on the balance tests will be kept confidential and will in no way affect my evaluation on the training program.

_____

Signature of Participant

_____

Date

_____

SIN of Participant

_____

Signature of Witness

_____

Signature of Interviewer

Appendix D

This appendix contains a guideline for a trained observer to rate observable symptoms associated with simulator sickness. Included are measures of skin pallor, sweating, yawning, nystagmus and loss of balance. Ratings for pallor, sweating and yawning are self explanatory. Nystagmus is rapid involuntary oscillations or rhythmical movement of the eye. This may be directly observed by having the trainee focus on an object to the far right, left, up, down. Measures of balance include the Sharpened Romberg (SR) and WOFEC tests. The SR test requires the participant to remain standing in a heel-to-toe posture with eyes closed, arms folded against the chest, and body erect for 60 seconds. Those who fail to remain in the position for the full 60 seconds on the first trial are given up to three additional trials. The WOFEC is similar but requires the participant to take ten steps, heel-to-toe, without sidestepping. The number of steps properly taken before sidestepping, stopping, opening eyes, or unfolding the arms is taken as the score.

INTERVIEWER DATA SHEET

Respondent Code Number	Date	Current Time	Simulator Run Start Time	Simulator Run Stop Time	Simulator Run Number

Questionnaire Instructions:

Check the appropriate blocks below to indicate the magnitude of any symptoms/reactions that you observed in the respondent. If the respondent experienced any unusual symptoms or reactions that are not listed below, record in the blank spaces at the bottom of the table and rate the magnitude of the symptom/reaction. Give objective tests and record the results at the bottom of this form.

Symptom/Reaction	Check One				Additional Comments (Write-in)
	Magnitude of Symptom/Reaction				
No. Description	Not Present	Mild	Moderate	Severe	
1. pallor					
2. sweating		Specks	Beads	Profuse	
3. yawning/apparent drowsiness					
4. loss of balance - WOFEC	30	27-29	23-26	22 or Less	
5. loss of balance - SR	240	180-239	120-179	119 or Less	
6. nystagmus					
7.					
8.					
9.					
10.					

SR:	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4	SCORE CALCULATION		
STOP WHEN 1 PERFECT TRIAL COMPLETED MAXIMUM 4 TRIALS					TRIAL 1 ONLY	60 X 4 =	240
					TRIALS 1 & 2	180 - TIME ON 1 =	
	—	—	—	—	TRIALS 1, 2 & 3	120 - TIME ON 1 - 2 =	
	60	60	60	60	ALL 4 TRIALS	TIME ON 1 - 2 - 3 - 4 =	
	SECONDS						

WOFEC:	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4	TRIAL 5	SCORE
STOP WHEN 3 PERFECT TRIALS COMPLETED MAXIMUM 5 TRIALS						SUM OF BEST 3 TRIALS
	—	—	—	—	—	—
	10	10	10	10	10	30
	STEPS					